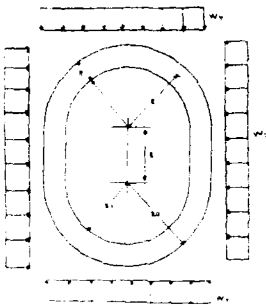

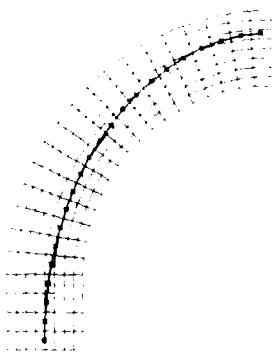

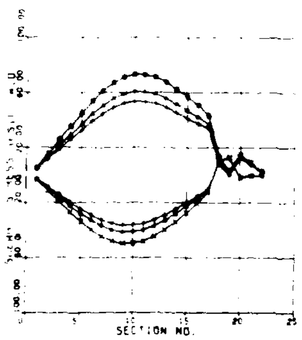

TECHNICAL REPORT SL-88-32

ANALYSIS OF STRESSES AND FORCE RESULTANTS IN OBLONG CONDUITS UNDER UNIFORMLY DISTRIBUTED LOADS

by

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Finite element techniques were used to evaluate the stresses and force resultants in oblong reinforced concrete conduits. Steel ratios were varied. The analyses showed that the presence of steel has little effect on the force resultants but does influence the stress distribution in the vicinity of the reinforcement. Tables of moment, thrust, and shear parameters for two shapes are included.

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PREFACE

This study was conducted by the Department of Civil Engineering (DCE), Ohio State University, under the sponsorship of Headquarters, US Army Corps of Engineers. The Technical Monitor was Dr. Tony Liu. Dr. Ranbir S. Sandhu, DCE, was the Principal Investigator. Mr. Chia-chi Chen, graduate assistant, DCE, performed the calculations and assisted with the compilation of the report.

The work was monitored by the US Army Engineer Waterways Experiment Station (WES) under the supervision of Messrs. Bryant Mather, Chief, Structures Laboratory (SL); James T. Ballard, Assistant Chief, SL; and Dr. Jimmy P. Balsara, Chief, Structural Mechanics Division (SMD), SL. Dr. Robert L. Hall, SMD, monitored the study.

COL Dwayne G. Lee, CE, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
kips (force) per square inch	6.894757	megapascals
pounds (force) per square inch	0.006894757	megapascals

SECTION I

INTRODUCTION

The purpose of this study was to evaluate the stresses and force resultants, under uniformly distributed loads, in two oblong reinforced concrete conduits, designed by the U. S. Army Waterway Experiment Station, with various steel ratios.

In a previous report [1], finite element solutions were compared with the exact solution for a circular conduit. Element QM4 was found to best combine accuracy and economy of solution. In the present research the procedure was applied to oblong conduits to study distribution of stresses and to generate tables for calculation of force resultants.

Section II describes the finite element models and lists the numerical results for stresses and force resultants of the problems. For design purpose, nondimensional factors for calculating the force resultants of conduits which have the same geometries as the two designed conduits are listed.

SECTION II

FINITE ELEMENT ANALYSIS OF OBLONG REINFORCED CONCRETE CONDUITS

2.1 THE FINITE ELEMENT MODELS

Two oblong reinforced concrete coduits designated as conduit No. 1 and No. 2 were analyzed under two uniformly distributed loading cases, viz, a unit horizontal load and a unit vertical load applied to the exterior surface. For any other uniformly distributed loading, the stresses and force resultants for the conduits can be obtained by superposing the solutions for these two loading cases.

The dimensions of the two conduits are shown in Figure 1. Three steel ratios, viz, 0.41%, 0.67%, 0.87% respectively equivelant to No. 6 bars with 6 inches spacing, No. 7 bars with 5-in.* spacing and No. 8 bars with 5 inches spacing were considered.

Finite element meshes for the two conduits are shown in Figures 2 and 3. Because of symmetry of the structure, only one quarter of the conduit was used in the calculations. QM4 element, introduced by Zienkiewicz et al. [2], was used for modeling the two reinforced concrete structures. This element was selected because of its excellent economy and accuracy in analysis of circular reinforced conduits [1].

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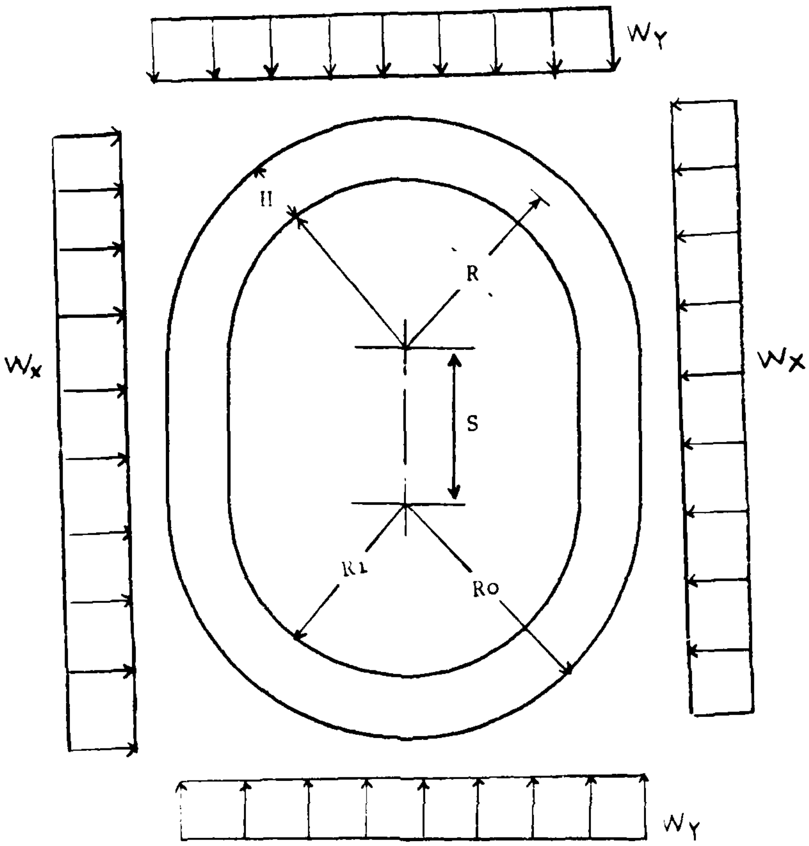
* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page VI.



Conduit NO.	R (FT)	H (FT)	S (FT)	WX (KSI)	WY (KSI)	Steel Cover (IN)	Steel ratio
1	9	3	6	1	0	4.5	.41%
				1	0	4.5	.67%
				1	0	4.5	.87%
				0	1	4.5	.41%
				0	1	4.5	.67%
				0	1	4.5	.87%
2	4.5	3	1.5	1	0	4.5	.41%
				1	0	4.5	.67%
				1	0	4.5	.87%
				0	1	4.5	.41%
				0	1	4.5	.67%
				0	1	4.5	.87%

Figure 1: Dimensions of the conduits

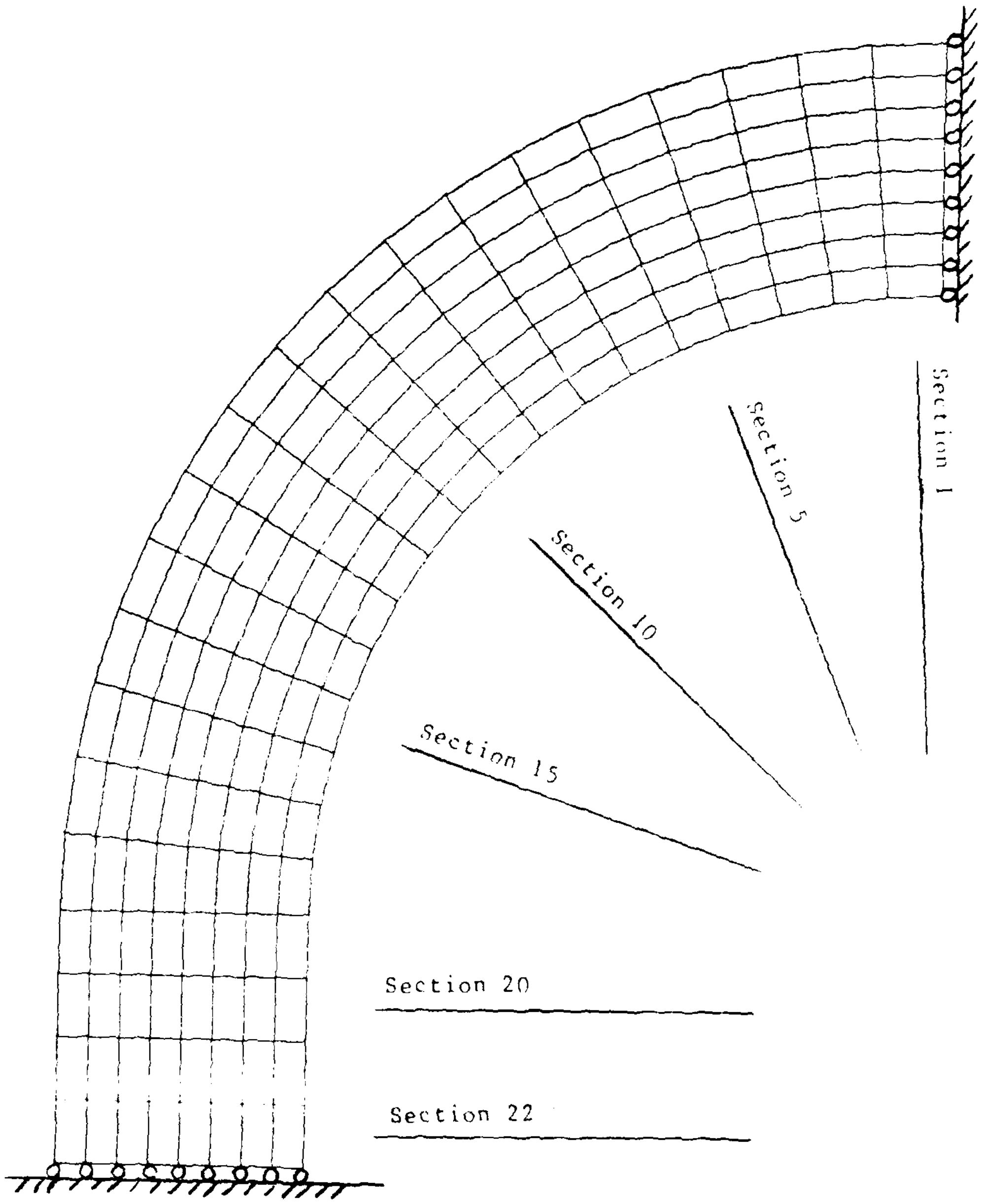


Figure 2: Finite element mesh for conduit 1

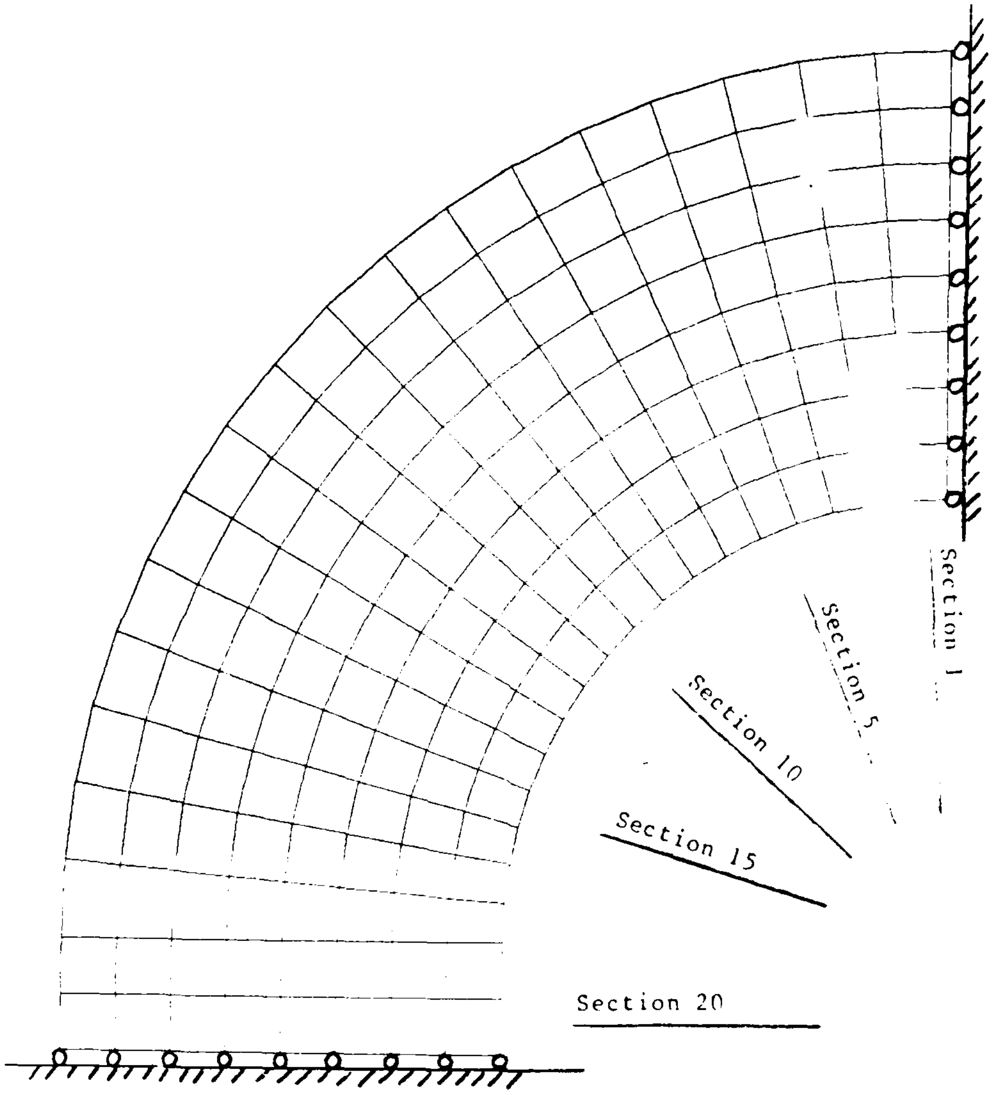


Figure 3: Finite element mesh for conduit 2

The conduits were assumed to be in plane strain state and a unit thickness was used in analysis. One-dimensional elements used to model the steel bars were assumed to be perfactly bonded to the concrete.

2.2 STRESS DISTRIBUTION IN THE CONDUITS

Tables 1 and 2 give the circumferential distribution of values of tangential stress at the centers of the innermost and the outermost elements of conduit No. 1, which are the most critical parts of the conduit, with various steel ratios under the two loading cases. Tables 3 and 4 list the values of radial shear stress at the centers of the innermost and the outermost elements of conduit No. 1 with various steel ratios under the two loading cases. Figures 4 through 7 illustrate the variation.

Tables 5 and 6 give the circumferential distribution of values of tangential stress at the centers of the innermost and the outermost elements of conduit No. 2, which are the most critical parts of the conduit, with various steel ratios under the two loading cases. Tables 7 and 8 list the values of radial shear stress at the centers of the innermost and the outermost elements of conduit No. 2 with various steel ratios under the two loading cases. Figures 8 through 11 illustrate the stress distribution.

It can be seen from these tables that the reinforcing steel helps relieve stresses in concrete in its vicinity. The more the steel used, the lower is the stress in the concrete around the steel.

TABLE 1

Tangential stress (psi) at the innermost element centers of conduit 1

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	-18590.	-15370.	-13540.	9372.	7674.	6723.
2	-18190.	-15050.	-13260.	9075.	7430.	6508.
3	-17420.	-14420.	-12700.	8494.	6951.	6087.
4	-16300.	-13490.	-11890.	7650.	6255.	5475.
5	-14860.	-12310.	-10850.	6573.	5366.	4692.
6	-13140.	-10890.	-9608.	5300.	4314.	3766.
7	-11190.	-9287.	-8195.	3872.	3133.	2725.
8	-9064.	-7530.	-6648.	2332.	1859.	1601.
9	-6804.	-5662.	-5004.	726.	529.	428.
10	-4460.	-3726.	-3299.	-901.	-820.	-761.
11	-2081.	-1761.	-1569.	-2505.	-2148.	-1933.
12	283.	191.	149.	-4040.	-3419.	-3054.
13	2586.	2090.	1820.	-5462.	-4596.	-4092.
14	4782.	3900.	3410.	-6731.	-5645.	-5016.
15	6831.	5588.	4894.	-7808.	-6536.	-5801.
16	8699.	7131.	6254.	-8665.	-7248.	-6432.
17	10320.	8493.	7466.	-9260.	-7756.	-6891.
18	11370.	9359.	8228.	-9374.	-7841.	-6958.
19	11820.	9684.	8484.	-9072.	-7548.	-6667.
20	12210.	10000.	8759.	-8892.	-7392.	-6523.
21	12660.	10390.	9111.	-8915.	-7428.	-6567.
22	12880.	10580.	9284.	-8927.	-7443.	-6583.

TABLE 2

Tangential stress (psi) at the outermost element centers of conduit 1

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	9717.	7878.	6854.	-8150.	-6755.	-5964.
2	9467.	7675.	6676.	-7971.	-6609.	-5836.
3	8976.	7274.	6326.	-7620.	-6323.	-5580.
4	8258.	6688.	5814.	-7111.	-5907.	-5221.
5	7335.	5934.	5154.	-6460.	-5375.	-4756.
6	6234.	5033.	4365.	-5692.	-4746.	-4204.
7	4983.	4007.	3465.	-4829.	-4039.	-3584.
8	3612.	2881.	2478.	-3900.	-3276.	-2915.
9	2151.	1681.	1424.	-2931.	-2480.	-2216.
10	631.	431.	327.	-1949.	-1672.	-1507.
11	-919.	-844.	-792.	-981.	-877.	-809.
12	-2469.	-2117.	-1910.	-55.	-116.	-141.
13	-3987.	-3364.	-3004.	803.	588.	477.
14	-5441.	-4558.	-4051.	1565.	1212.	1025.
15	-6799.	-5671.	-5027.	2204.	1736.	1483.
16	-8028.	-6674.	-5902.	2699.	2137.	1833.
17	-9103.	-7531.	-6638.	3037.	2403.	2059.
18	-10270.	-8475.	-7457.	3315.	2619.	2242.
19	-11500.	-9505.	-8377.	3557.	2815.	2412.
20	-12340.	-10190.	-8982.	3662.	2892.	2474.
21	-12760.	-10510.	-9248.	3658.	2878.	2454.
22	-12960.	-10670.	-9381.	3648.	2866.	2441.

TABLE 3

Radial shear stress (psi) at the innermost element centers of conduit 1

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	51.3	42.1	36.8	-39.7	-32.6	-28.7
2	153.8	126.0	110.5	-118.5	-97.6	-85.8
3	255.2	209.4	183.8	-195.8	-161.3	-141.9
4	354.0	291.1	255.7	-269.6	-222.6	-196.0
5	447.9	369.0	324.5	-337.9	-279.4	-246.3
6	533.7	440.6	387.9	-397.7	-329.4	-290.8
7	607.8	502.6	442.9	-446.1	-370.1	-327.0
8	666.7	551.9	486.8	-480.3	-399.0	-352.8
9	707.6	586.1	517.2	-498.3	-414.1	-366.3
10	728.5	603.5	532.5	-498.7	-414.6	-366.7
11	728.9	603.6	532.4	-481.7	-400.2	-353.9
12	709.8	587.1	517.5	-448.2	-372.0	-328.7
13	673.7	556.4	489.9	-400.6	-332.0	-293.1
14	624.5	514.9	452.9	-342.0	-283.0	-249.5
15	567.4	468.0	411.8	-276.2	-228.6	-201.7
16	507.4	422.4	374.4	-207.7	-174.7	-156.0
17	429.1	366.6	331.1	-129.8	-115.9	-107.8
18	136.0	98.3	76.6	101.7	101.6	102.1
19	30.7	8.9	-4.0	128.5	121.6	118.2
20	149.7	133.3	123.6	-13.2	-19.7	-23.1
21	91.6	78.7	71.3	-6.7	-8.2	-8.9
22	30.0	25.0	22.2	-1.6	-1.5	-1.5

TABLE 4

Radial shear stress (psi) at the outermost element centers of conduit 1

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	68.2	63.9	61.4	-62.2	-59.0	-57.2
2	203.8	190.6	183.3	-185.5	-175.9	-170.5
3	336.2	314.3	302.1	-305.0	-289.0	-280.1
4	462.9	432.3	415.2	-417.6	-395.5	-383.2
5	580.2	541.3	519.5	-520.0	-492.2	-476.7
6	684.2	637.6	611.4	-608.3	-575.5	-557.1
7	770.6	717.1	687.1	-678.9	-641.9	-621.2
8	835.3	776.4	743.1	-728.3	-688.4	-665.9
9	875.2	812.3	776.8	-754.0	-712.5	-689.1
10	888.1	823.1	786.3	-754.6	-713.0	-689.6
11	873.7	808.3	771.4	-730.0	-689.8	-667.3
12	833.1	769.1	733.0	-681.5	-644.2	-623.2
13	768.4	707.5	673.1	-611.4	-578.2	-559.6
14	682.8	626.2	594.4	-522.6	-494.5	-478.8
15	580.3	529.2	500.5	-418.8	-396.5	-384.0
16	464.7	418.2	392.1	-303.7	-286.9	-277.5
17	338.0	290.3	263.6	-183.3	-169.8	-162.4
18	355.8	304.8	276.5	-115.0	-101.4	-94.0
19	326.9	279.9	253.9	-61.5	-50.5	-44.4
20	135.5	100.9	81.6	0.6	5.5	8.1
21	76.8	59.3	49.6	5.0	6.1	6.6
22	25.8	20.6	17.7	1.8	1.8	1.9

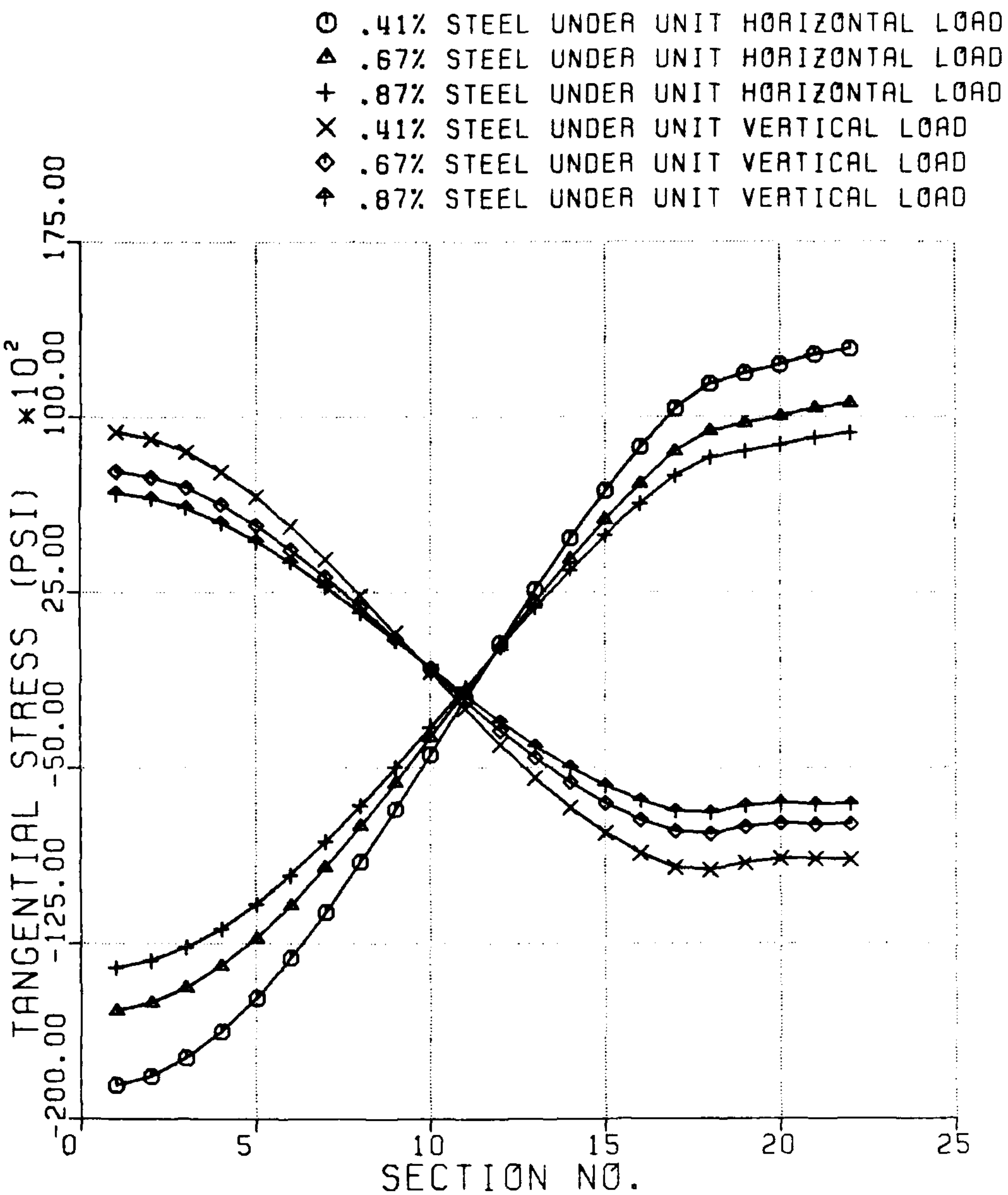


Figure 4: Tangential stress (psi) at the innermost element centers of conduit 1

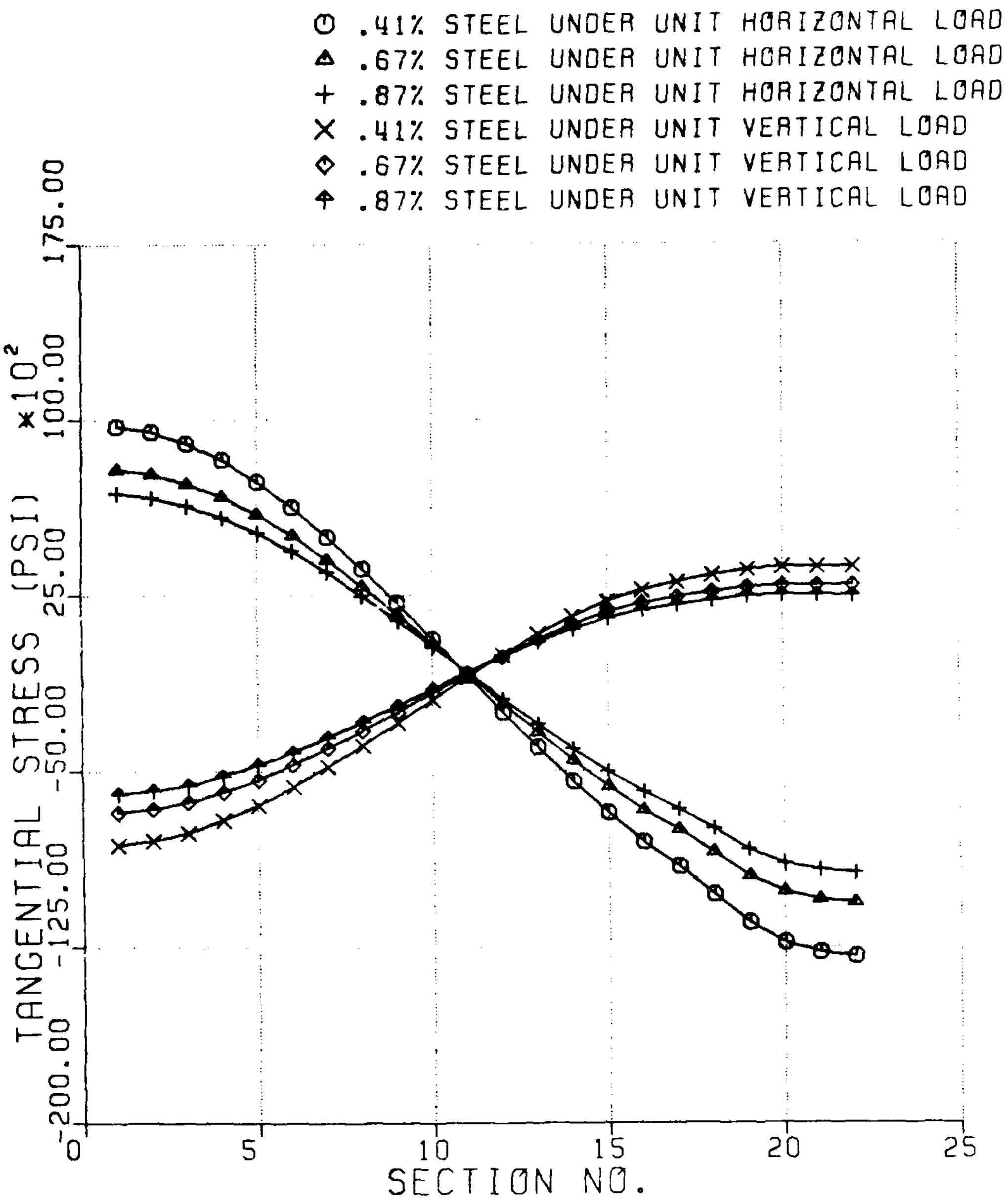


Figure 5: Tangential stress (psi) at the outermost element centers of conduit 1

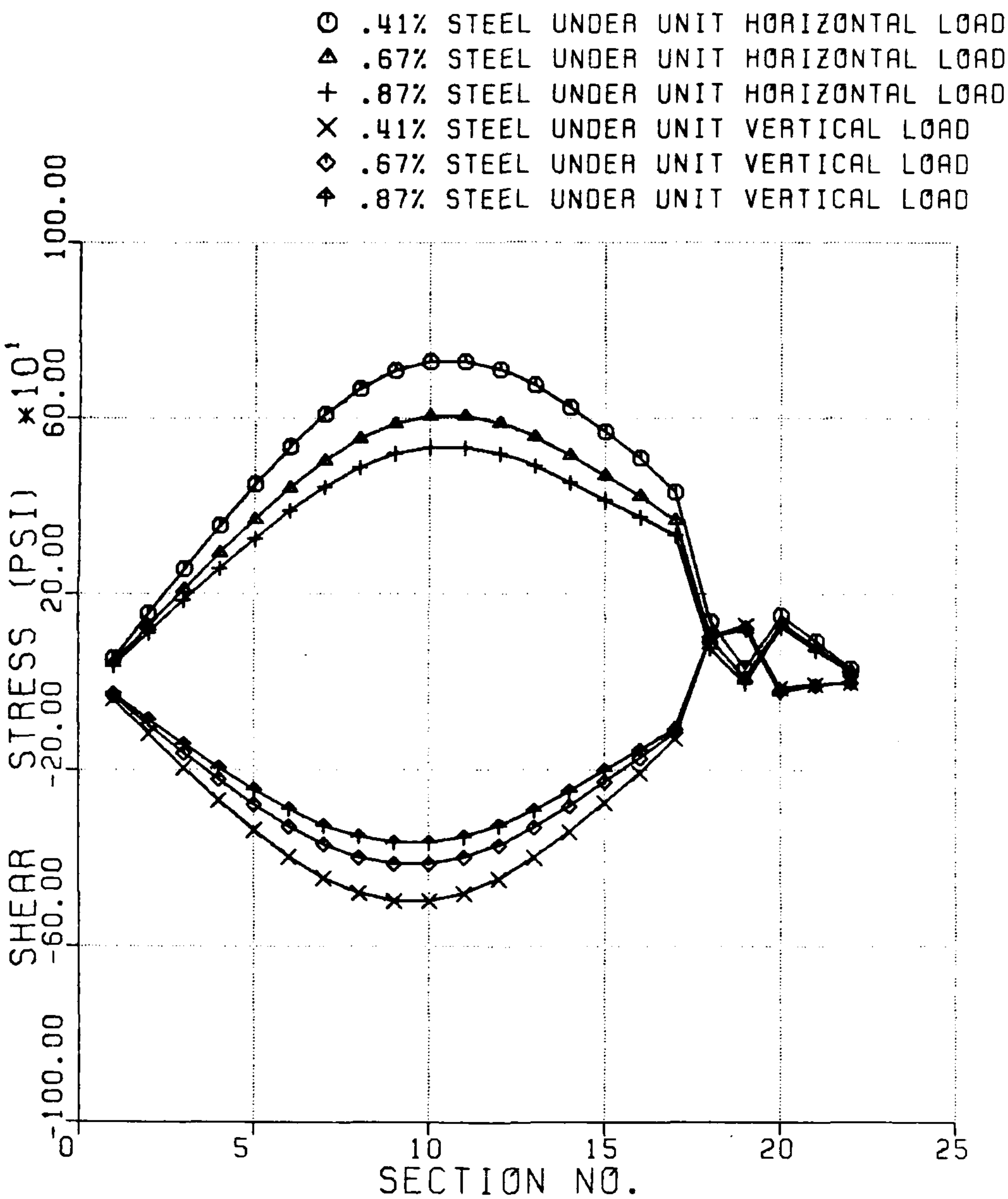


Figure 6: Radial shear stress (psi) at the innermost element centers of conduit 1

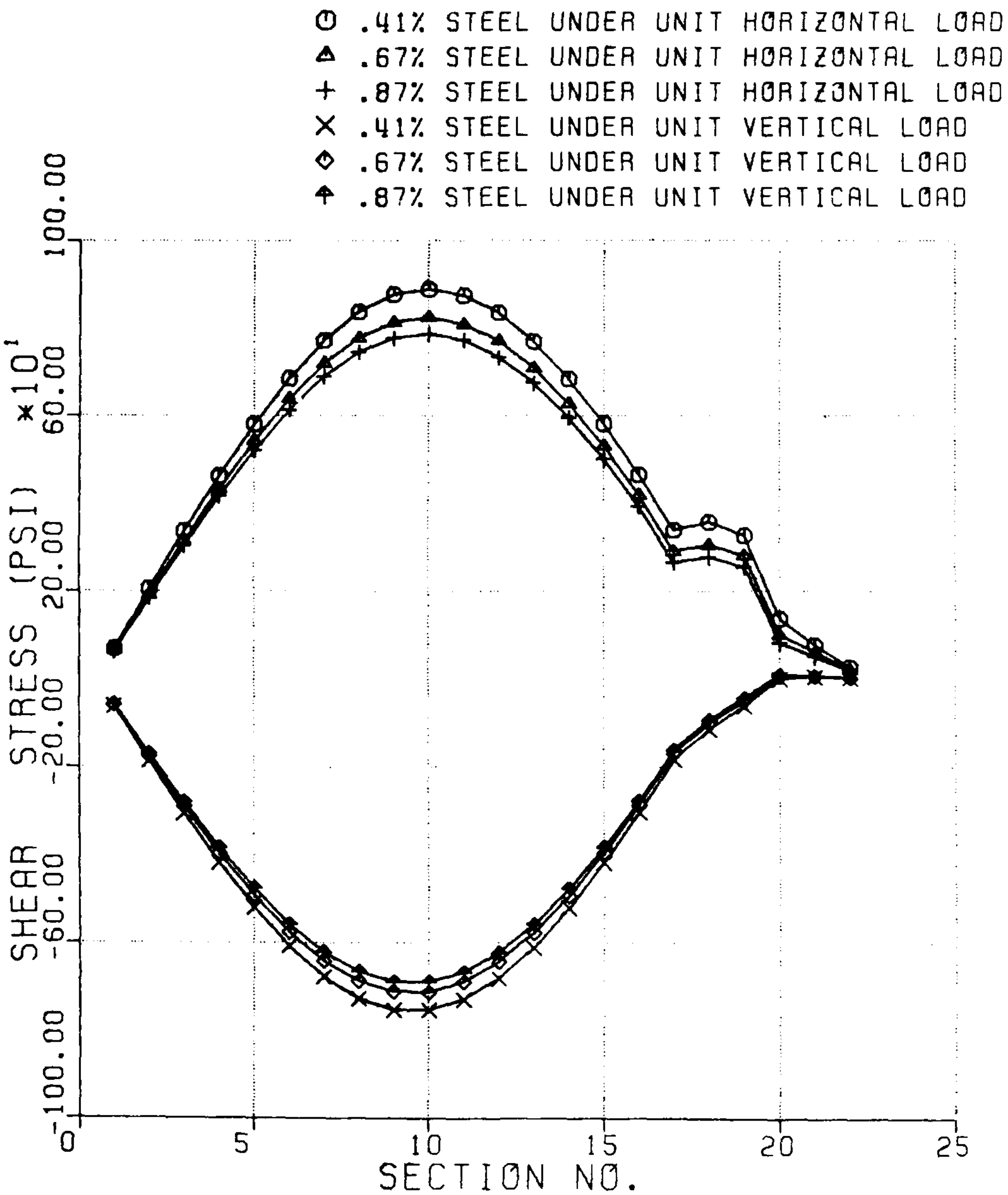


Figure 7: Radial shear stress (psi) at the outermost element centers of conduit 1

TABLE 5

Tangential stress (psi) at the innermost element centers of conduit 2

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	-4908.	-4145.	-3707.	2212.	1865.	1675.
2	-4806.	-4059.	-3630.	2123	1790.	1608.
3	-4607.	-3890.	-3479.	1949.	1642.	1475.
4	-4313.	-3642.	-3256.	1693.	1425.	1280.
5	-3934.	-3322.	-2969.	1364.	1146.	1030.
6	-3478.	-2936.	-2624.	971.	813.	730.
7	-2958.	-2497.	-2230.	526.	435.	390.
8	-2388.	-2015.	-1798.	41.	23.	20.
9	-1783.	-1504.	-1340.	-468.	-408.	-368.
10	-1159.	-977.	-868.	-985.	-848.	-763.
11	-534.	-449.	-394.	-1496.	-1281.	-1153.
12	77.	68.	69.	-1983.	-1696.	-1527.
13	656.	558.	509.	-2433.	-2079.	-1872.
14	1189.	1009.	914.	-2830.	-2419.	-2179.
15	1657.	1407.	1272.	-3159.	-2701.	-2435.
16	2041.	1733.	1565.	-3401.	-2910.	-2624.
17	2313.	1961.	1769.	-3526.	-3013.	-2715.
18	2430.	2049.	1838.	-3483.	-2958.	-2652.
19	2428.	2027.	1805.	-3318.	-2784.	-2473.
20	2393.	1981.	1753.	-3188.	-2651.	-2338.

TABLE 6

Tangential stress (psi) at the outermost element centers of conduit 2

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	574.	425.	348.	-1624.	-1395.	-1266.
2	543.	399.	325.	-1600.	-1375.	-1247.
3	480.	347.	279.	-1552.	-1335.	-1212.
4	389.	271.	211.	-1482.	-1277.	-1160.
5	270.	173.	124.	-1392.	-1202.	-1093.
6	128.	54.	19.	-1285.	-1113.	-1014.
7	-34.	-80.	-101.	-1164.	-1012.	-924.
8	-213.	-229.	-233.	-1033.	-903.	-827.
9	-403.	-387.	-374.	-896.	-789.	-725.
10	-600.	-551.	-519.	-758.	-673.	-622.
11	-800.	-717.	-667.	-621.	-560.	-521.
12	-997.	-880.	-812.	-492.	-452.	-425.
13	-1187.	-1038.	-951.	-373.	-354.	-338.
14	-1367.	-1186.	-1082.	-268.	-268.	-261.
15	-1534.	-1322.	-1201.	-178.	-195.	-198.
16	-1689.	-1446.	-1308.	-103.	-135.	-146.
17	-1840.	-1566.	-1410.	-37.	-83.	-102.
18	-2032.	-1728.	-1557.	36.	-24.	-52.
19	-2226.	-1901.	-1719.	105.	31.	-3.
20	-2334.	-1999.	-1811.	144.	62.	25.

TABLE 7

Radial shear stress (psi) at the innermost element centers of conduit 2

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	36.6	31.2	28.2	-31.8	-27.3	-24.7
2	108.5	92.5	83.5	-94.4	-80.3	-73.2
3	177.0	150.9	136.2	-153.7	-131.6	-119.1
4	240.0	204.6	184.5	-207.9	-177.9	-161.0
5	295.8	252.0	227.2	-255.3	-218.4	-197.5
6	343.1	292.1	263.3	-294.6	-251.9	-227.8
7	380.8	324.0	292.0	-324.8	-277.7	-251.0
8	408.4	347.4	312.9	-345.5	-295.3	-266.9
9	425.7	362.0	325.9	-356.2	-304.5	-275.2
10	432.4	367.7	331.1	-356.8	-305.1	-275.9
11	428.7	364.6	328.4	-347.4	-297.4	-269.1
12	414.5	352.9	318.0	-328.1	-281.4	-255.0
13	389.6	332.3	299.9	-298.8	-257.2	-233.6
14	353.4	302.3	273.3	-259.0	-224.2	-204.3
15	303.5	260.4	235.9	-206.4	-179.8	-164.5
16	235.0	201.4	182.2	-134.9	-117.3	-107.9
17	136.3	112.6	99.0	-28.6	-18.7	-12.7
18	-12.3	-27.0	-35.7	141.3	148.5	152.9
19	-60.5	-68.2	-72.9	150.7	154.2	156.4
20	-10.5	-12.7	-14.1	32.6	32.2	32.1

TABLE 8

Radial shear stress (psi) at the outermost element centers of conduit 2

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	52.7	51.7	51.1	-51.4	-50.5	-50.1
2	156.7	153.6	151.9	-152.5	-150.2	-148.9
3	256.1	251.0	248.2	-249.2	-245.3	-243.2
4	348.1	341.1	337.3	-338.5	-333.1	-330.2
5	429.9	421.2	416.4	-417.6	-411.0	-407.4
6	499.2	488.9	483.3	-484.1	-476.5	-472.3
7	553.6	542.1	535.7	-536.0	-527.5	-522.9
8	591.6	579.1	572.2	-571.5	-562.4	-557.5
9	611.9	598.6	591.4	-589.5	-580.1	-575.0
10	613.8	600.2	592.8	-589.3	-579.9	-574.8
11	597.4	583.8	576.3	-571.0	-561.9	-557.0
12	563.1	549.8	542.4	-535.2	-526.6	-522.0
13	512.4	499.5	492.4	-483.1	-475.2	-471.0
14	447.0	434.6	427.7	-416.7	-409.6	-405.8
15	369.5	357.3	350.6	-338.6	-332.2	-328.8
16	283.5	271.1	264.3	-252.2	-246.4	-243.3
17	199.1	186.3	179.4	-163.5	-157.9	-155.0
18	149.1	138.0	132.1	-83.8	-76.8	-72.9
19	102.4	94.7	90.7	-35.8	-29.7	-26.1
20	29.6	26.3	24.6	-10.9	-9.1	-8.1

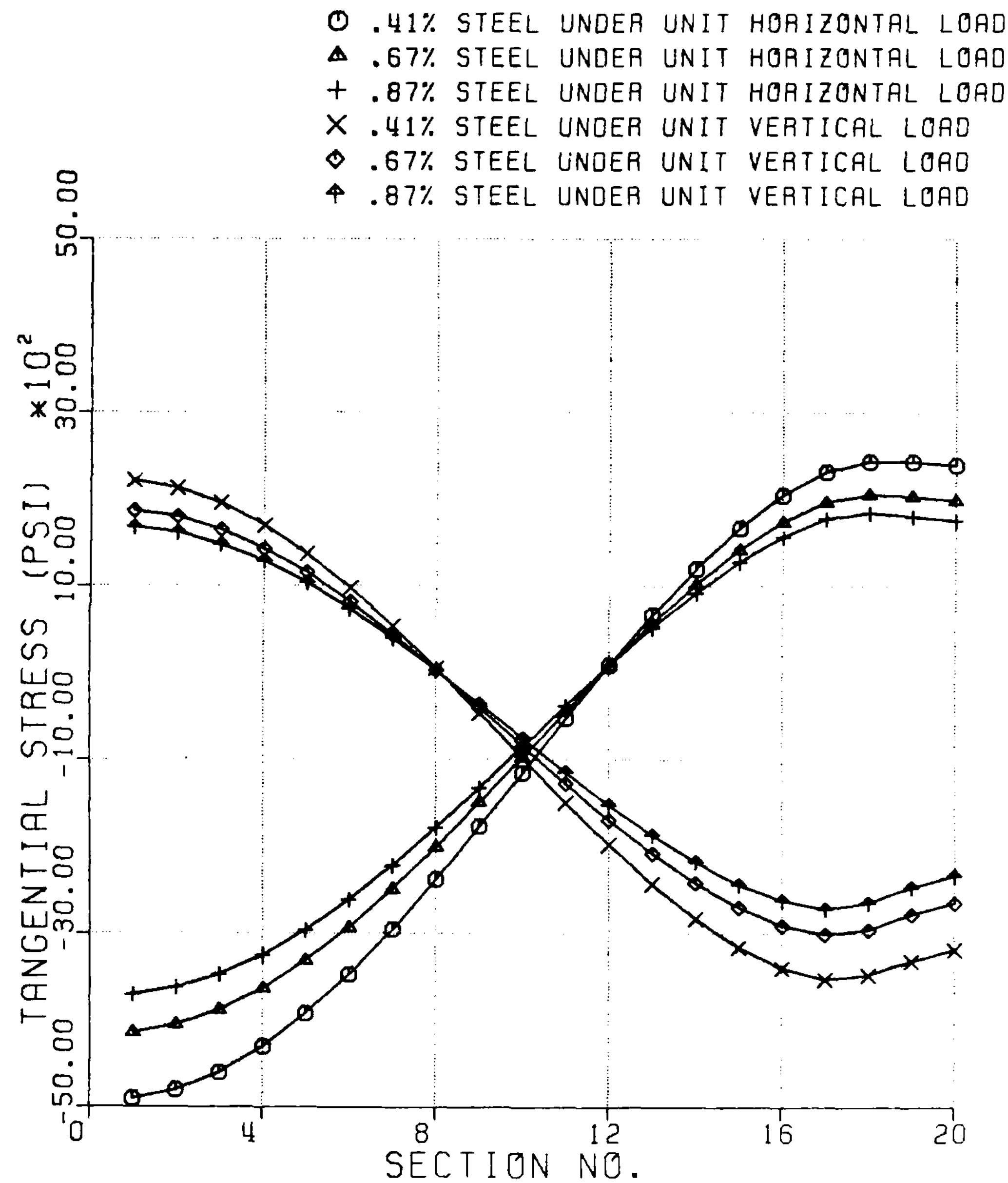


Figure 8: Tangential stress (psi) at the innermost element centers of conduit 2

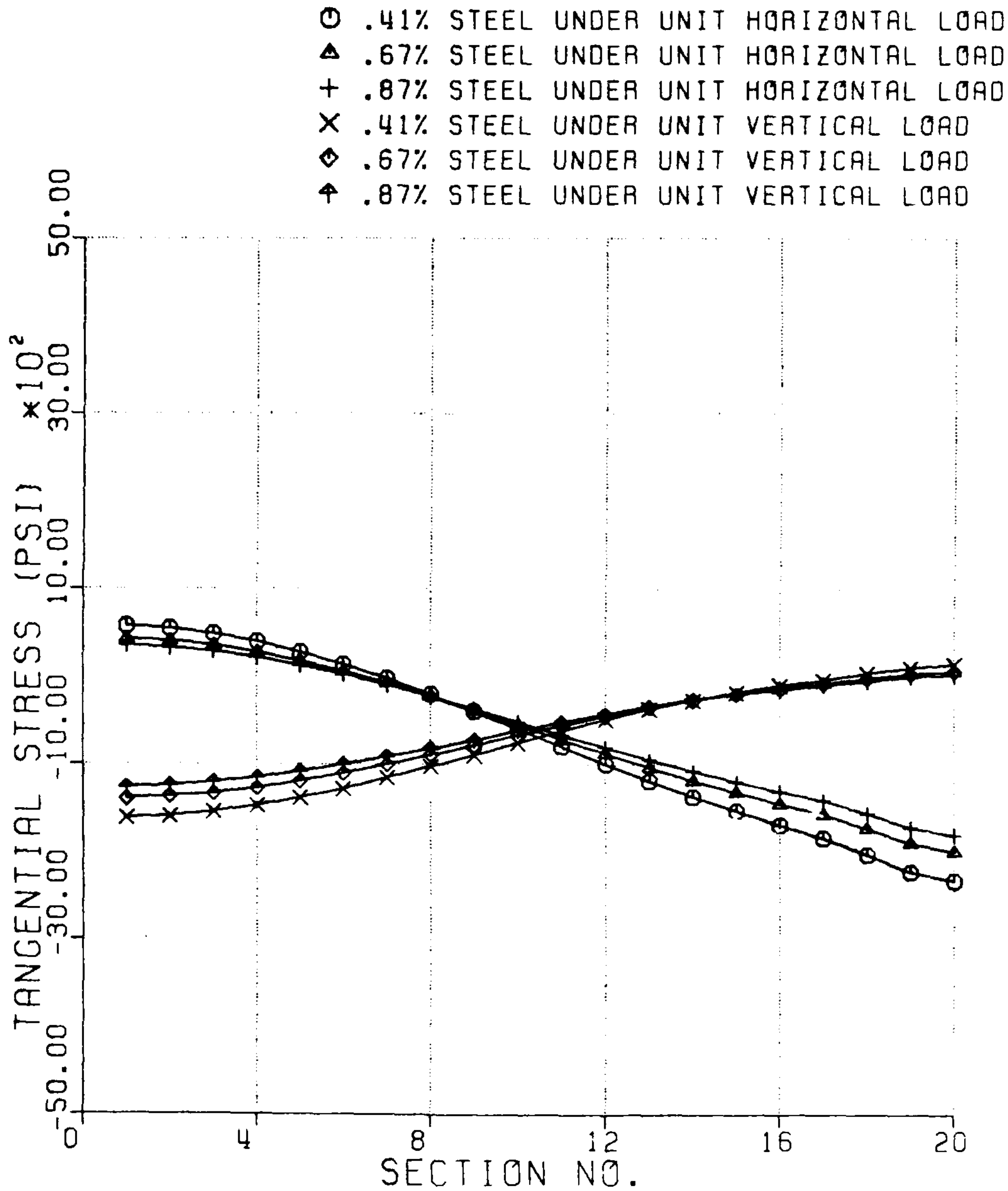


Figure 9: Tangential stress (psi) at the outermost element centers of conduit 2

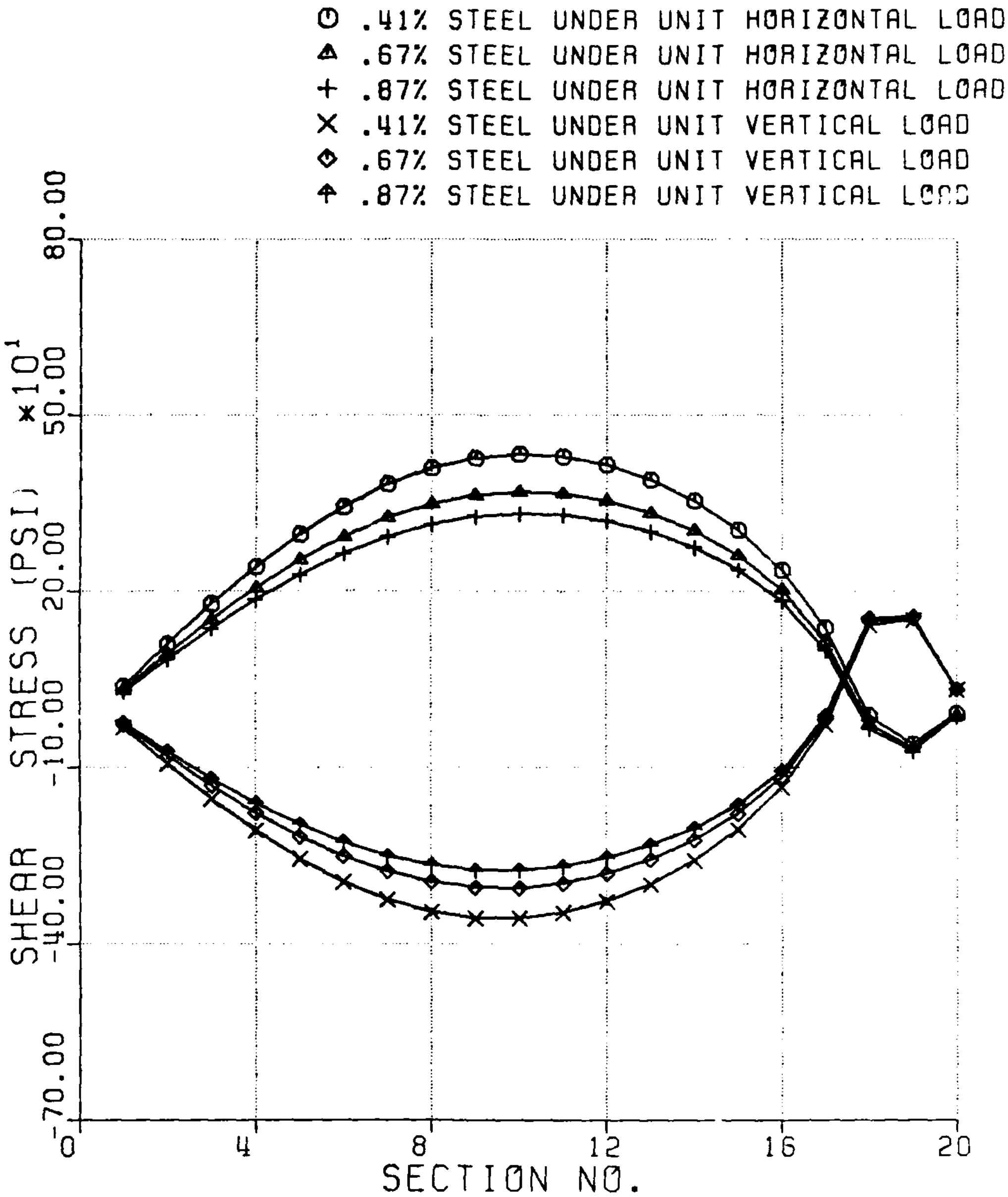


Figure 10: Radial shear stress (psi) at the innermost element centers of conduit 2

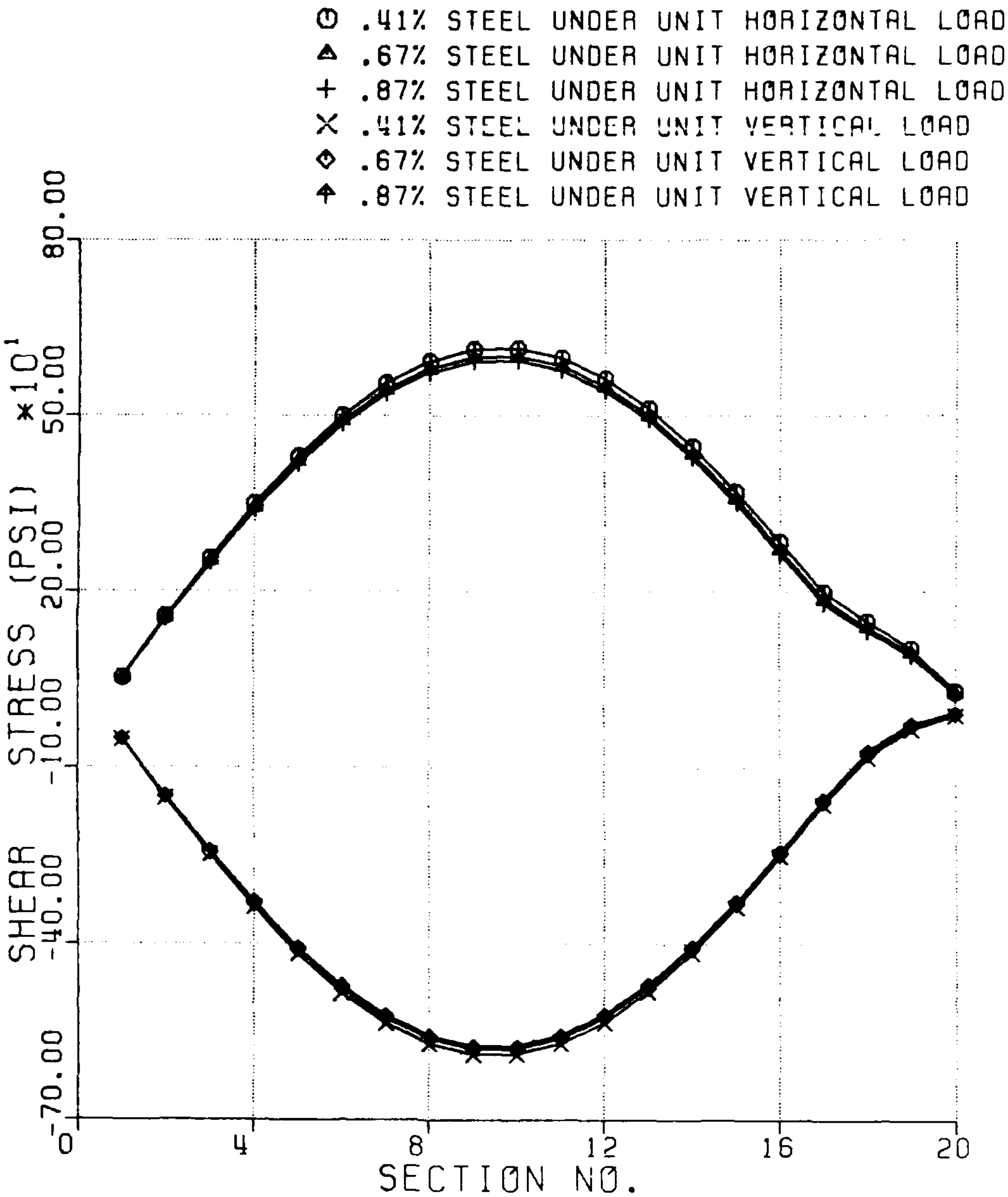


Figure 11: Radial shear stress (psi) at the outermost element centers of conduit 2

The finite element results for distribution of radial shear stress show an oscillatory variation near the horizontal diameter in stress along the centers of the innermost elements. All other stresses vary smoothly with angle around the circumference.

2.3 FORCE RESULTANTS

Numerical values of bending moment, shear force, and thrust respectively at various sections of a unit thickness (inch) of conduit No. 1 with various steel ratios under the two loading cases are listed in Tables 9 through 11. Figures 12 and 13 show the lines of thrust for conduit No. 1 with horizontal load over vertical load ratios equal to 0.25 and 0.5 respectively.

Tables 12 through 14 list the numerical values of bending moment, shear force, and thrust respectively at various sections of a unit thickness (inch) of conduit No. 2 with various steel ratios under the two loading cases. Figures 14 and 15 show the lines of thrust for conduit No. 2 with horizontal load over vertical load ratios equal to 0.25 and 0.5 respectively.

The finite element results show that the values of shear force, thrust and bending moment are almost the same for a conduit with different steel ratios. The difference among these values is so small that it can be ignored in design.

TABLE 9

Bending moment (kip-in) at various sections of conduit 1

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	5227.	5234.	5237.	-3217.	-3219.	-3220.
2	5109.	5117.	5120.	-3130.	-3132.	-3134.
3	4878.	4886.	4890.	-2959.	-2962.	-2964.
4	4540.	4549.	4553.	-2712.	-2715.	-2717.
5	4105.	4115.	4120.	-2395.	-2399.	-2401.
6	3586.	3596.	3601.	-2020.	-2024.	-2026.
7	2997.	3006.	3010.	-1600.	-1602.	-1604.
8	2352.	2359.	2362.	-1146.	-1147.	-1148.
9	1665.	1669.	1671.	-673.	-672.	-671.
10	951.	953.	952.	-193.	-190.	-188.
11	226.	224.	222.	280.	285.	288.
12	-497.	-502.	-506.	732.	739.	743.
13	-1202.	-1209.	-1215.	1151.	1159.	1163.
14	-1876.	-1885.	-1891.	1523.	1532.	1537.
15	-2504.	-2514.	-2521.	1838.	1847.	1851.
16	-3074.	-3084.	-3091.	2084.	2092.	2097.
17	-3574.	-3584.	-3591.	2253.	2261.	2266.
18	-3997.	-4007.	-4014.	2341.	2349.	2353.
19	-4331.	-4342.	-4349.	2366.	2374.	2379.
20	-4571.	-4583.	-4590.	2366.	2374.	2379.
21	-4731.	-4743.	-4751.	2366.	2374.	2379.
22	-4812.	-4824.	-4832.	2366.	2374.	2379.

TABLE 10

Shear force (kip) at various sections conduit 1

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	7.11	7.10	7.09	-5.52	-5.51	-5.51
2	21.15	21.11	21.10	-16.38	-16.37	-16.36
3	34.62	34.57	34.55	-26.74	-26.71	-26.69
4	47.19	47.13	47.10	-36.25	-36.22	-36.17
5	58.53	58.48	58.45	-44.65	-44.62	-44.60
6	68.38	68.34	68.32	-51.67	-51.64	-51.63
7	76.52	76.49	76.47	-57.11	-57.10	-57.09
8	82.77	82.75	82.74	-60.82	-60.81	-60.81
9	87.02	87.02	87.01	-62.70	-62.70	-62.69
10	89.21	89.21	89.21	-62.69	-62.69	-62.69
11	89.32	89.32	89.32	-60.79	-60.79	-60.79
12	87.40	87.39	87.39	-57.07	-57.06	-57.06
13	83.53	83.51	83.50	-51.61	-51.60	-51.59
14	77.85	77.82	77.81	-44.59	-44.57	-44.56
15	70.54	70.51	70.50	-36.20	-36.18	-36.17
16	61.86	61.83	61.81	-26.70	-26.68	-26.66
17	52.09	52.07	52.06	-16.38	-16.36	-16.35
18	41.56	41.56	41.64	-5.56	-5.56	-5.56
19	31.50	31.50	31.50	0.00	0.00	0.00
20	22.50	22.50	22.50	0.00	0.00	0.00
21	13.50	13.50	13.50	0.00	0.00	0.00
22	4.50	4.50	4.50	0.00	0.00	0.00

TABLE 11

Thrust (kip) at various sections of conduit 1

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	-161.2	-161.2	-161.3	-0.6	-0.5	-0.5
2	-159.0	-159.0	-159.1	-2.5	-2.4	-2.4
3	-154.6	-154.7	-154.8	-6.3	-6.2	-6.2
4	-148.3	-148.4	-148.4	-11.8	-11.7	-11.7
5	-140.1	-140.2	-140.3	-18.9	-18.8	-18.7
6	-130.4	-130.5	-130.6	-27.2	-27.2	-27.1
7	-119.4	-119.5	-119.5	-36.7	-36.6	-36.6
8	-107.3	-107.4	-107.5	-46.9	-46.9	-46.9
9	-94.6	-94.7	-94.7	-57.7	-57.6	-57.6
10	-81.6	-81.6	-81.7	-68.5	-68.5	-68.5
11	-68.6	-68.6	-68.6	-79.2	-79.2	-79.2
12	-55.8	-55.8	-55.8	-89.5	-89.5	-89.5
13	-43.7	-43.7	-43.6	-98.9	-98.9	-98.9
14	-32.5	-32.5	-32.5	-107.3	-107.3	-107.3
15	-22.6	-22.5	-22.5	-114.3	-114.3	-114.4
16	-14.1	-14.0	-14.0	-119.8	-119.8	-119.9
17	-7.3	-7.2	-7.1	-123.6	-123.6	-123.6
18	-2.2	-2.2	-2.1	-125.5	-125.5	-125.5
19	0.0	0.0	0.0	-126.0	-126.0	-126.0
20	0.0	0.0	0.0	-126.0	-126.0	-126.0
21	0.0	0.0	0.0	-126.0	-126.0	-126.0
22	0.0	0.0	0.0	-126.0	-126.0	-126.0

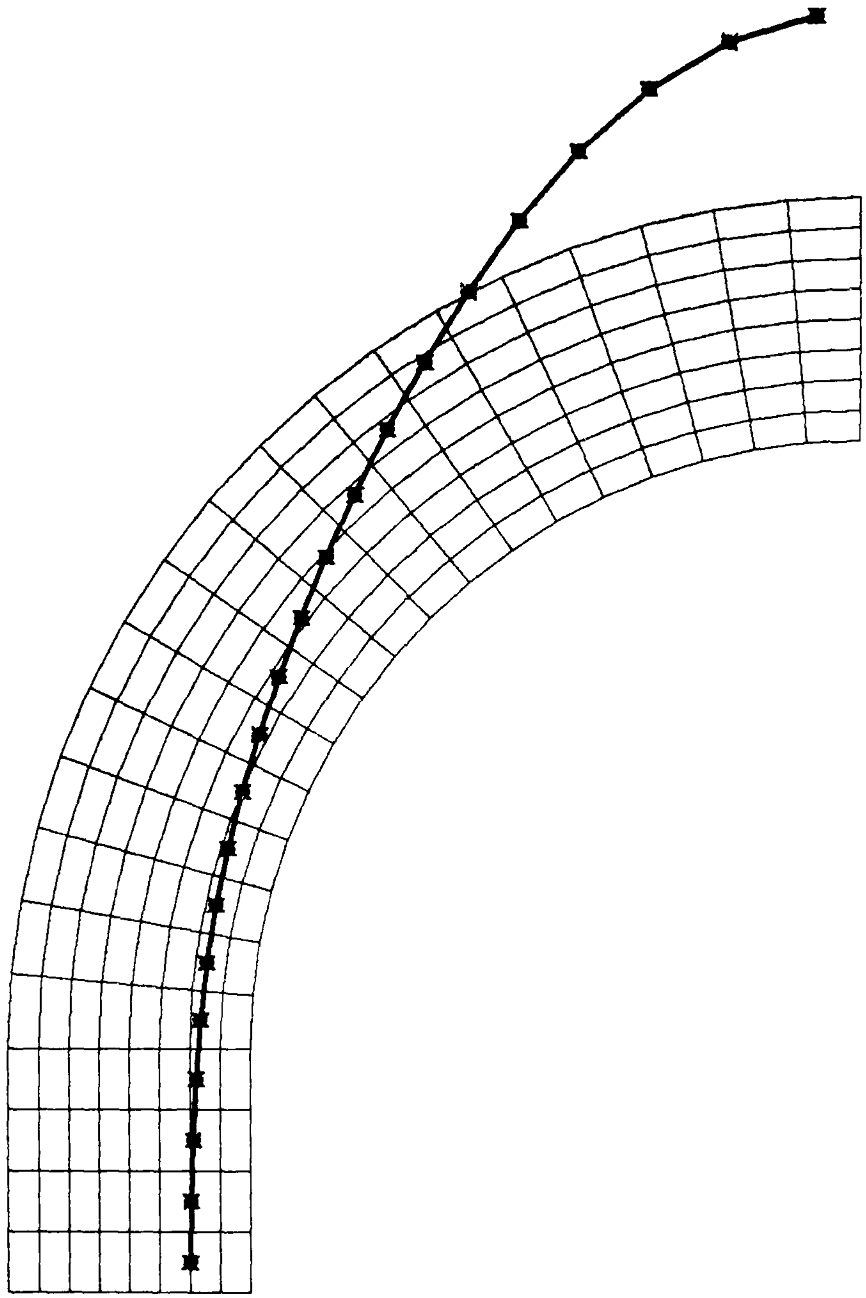


Figure 12: Line of thrust for conduit 1 with Wx/Wy = 0.25

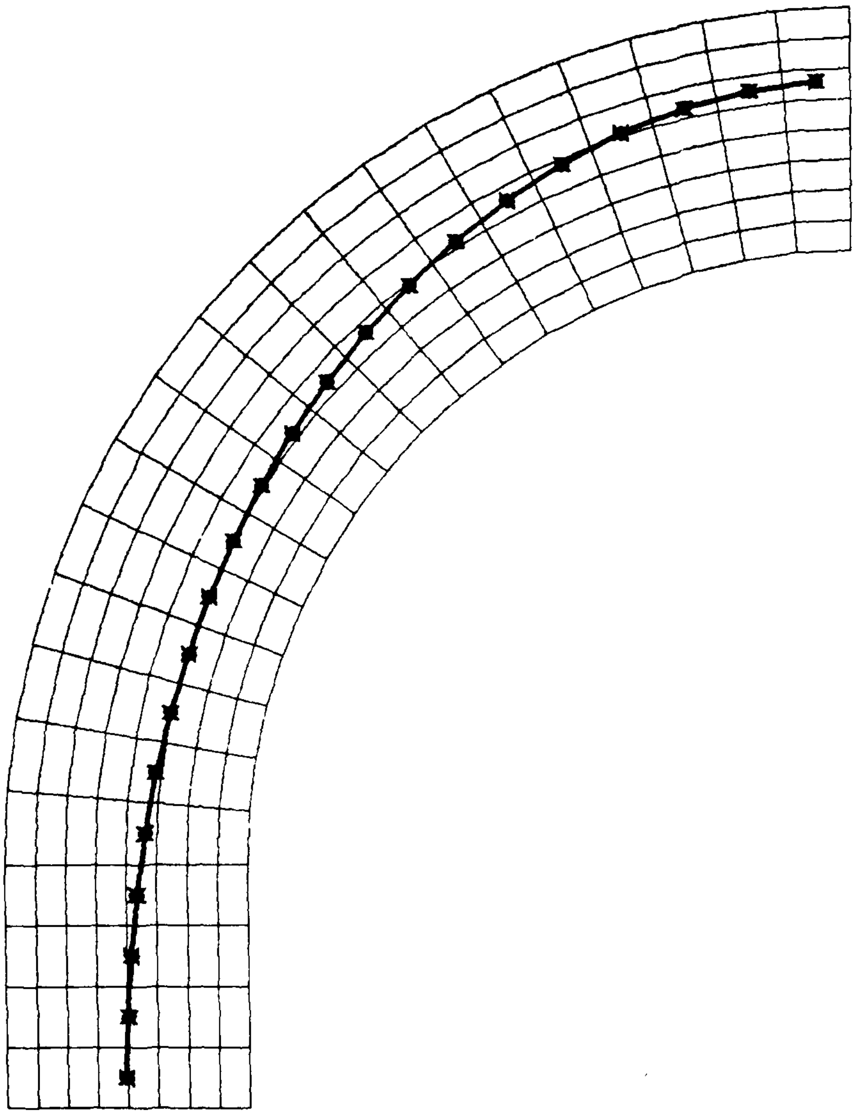


Figure 13: Line of thrust for conduit 1 with Wx/Wy = 0.50

TABLE 12

Bending moment (kip-in) at various sections of conduit 2

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	949.9	947.9	945.1	-646.5	-648.9	-651.4
2	927.1	925.0	922.1	-627.3	-629.7	-632.1
3	882.0	879.8	876.9	-589.5	-591.7	-594.2
4	815.9	813.6	810.6	-534.1	-536.3	-538.7
5	730.5	728.0	724.9	-463.0	-465.0	-467.3
6	628.0	625.3	622.1	-378.1	-380.0	-382.2
7	511.2	508.3	505.0	-282.2	-283.9	-286.0
8	383.2	380.0	376.5	-178.1	-179.2	-181.5
9	247.2	243.7	240.1	-68.9	-70.2	-72.1
10	106.8	103.1	99.4	41.9	40.8	39.1
11	-34.4	-38.3	-42.2	151.1	150.2	148.5
12	-172.7	-176.9	-181.0	255.2	254.5	253.0
13	-304.8	-309.3	-313.5	351.1	350.6	349.2
14	-427.5	-432.2	-436.5	435.9	435.6	434.2
15	-538.0	-542.9	-547.3	507.1	506.9	505.6
16	-633.8	-638.9	-643.4	562.6	562.4	561.2
17	-713.1	-718.3	-722.9	600.7	600.7	599.5
18	-774.6	-779.9	-784.6	620.7	620.8	619.6
19	-817.1	-822.5	-827.2	627.5	627.5	626.4
20	-837.3	-842.7	-847.5	627.9	627.9	626.8

TABLE 13

Shear force (kip) at various sections of conduit 2

SECTION NO.	HORIZONTAL LOAD = 1 KSI .41%STEEL	.67%STEEL	.87%STEEL	VERTICAL LOAD = 1 KSI .41%STEEL	.67%STEEL	.87%STEEL
1	3.52	3.52	3.52	-3.13	-3.13	-3.13
2	10.47	10.47	10.47	-9.30	-9.30	-9.30
3	17.13	17.31	17.31	-15.19	-15.19	-15.19
4	23.32	23.32	23.32	-20.62	-20.62	-20.62
5	28.85	28.85	28.85	-25.42	-25.42	-25.42
6	33.59	33.59	33.59	-29.45	-29.45	-29.45
7	37.41	37.41	37.41	-32.58	-32.58	-32.58
8	40.20	40.19	40.19	-34.72	-34.72	-34.72
9	41.89	41.88	41.88	-35.81	-35.81	-35.81
10	42.44	42.44	42.44	-35.81	-35.81	-35.81
11	41.86	41.85	41.85	-34.72	-34.72	-34.72
12	40.16	40.16	40.16	-32.58	-32.58	-32.58
13	37.42	37.42	37.42	-29.45	-29.45	-29.45
14	33.72	33.72	33.72	-25.42	-25.42	-25.42
15	29.19	29.19	29.19	-20.62	-20.62	-20.62
16	23.97	23.97	23.97	-15.20	-15.20	-15.20
17	18.23	18.23	18.23	-9.32	-9.32	-9.32
18	12.13	12.14	12.14	-3.15	-3.15	-3.15
19	6.75	6.75	6.75	0.00	0.00	0.00
20	2.25	2.25	2.25	0.00	0.00	0.00

TABLE 14

Thrust (kip) at various sections of conduit 2

SECTION	HORIZONTAL LOAD = 1 KSI			VERTICAL LOAD = 1 KSI		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	-80.59	-80.62	-80.64	-0.31	-0.29	-0.27
2	-79.44	-79.47	-79.48	-1.40	-1.37	-1.36
3	-77.17	-77.20	-77.21	-3.53	-3.51	-3.50
4	-73.85	-73.87	-73.89	-6.65	-6.63	-6.62
5	-69.57	-69.59	-69.61	-10.66	-10.65	-10.64
6	-64.46	-64.48	-64.49	-15.44	-15.43	-15.42
7	-58.67	-58.68	-58.69	-20.85	-20.84	-20.83
8	-52.35	-52.37	-52.37	-26.72	-26.71	-26.71
9	-45.71	-45.71	-45.72	-32.87	-32.86	-32.86
10	-38.91	-38.91	-38.92	-39.11	-39.11	-39.11
11	-32.17	-32.17	-32.16	-45.26	-45.27	-45.27
12	-25.67	-25.66	-25.65	-51.13	-51.14	-51.14
13	-19.59	-19.57	-19.57	-56.54	-56.55	-56.55
14	-14.10	-14.09	-14.08	-61.32	-61.33	-61.34
15	-9.36	-9.34	-9.33	-65.33	-65.35	-65.35
16	-5.49	-5.47	-5.45	-68.45	-68.47	-68.48
17	-2.59	-2.56	-2.55	-70.59	-70.61	-70.62
18	-0.72	-0.69	-0.68	-71.69	-71.71	-71.71
19	0.00	0.00	0.00	-72.00	-72.00	-72.00
20	0.00	0.00	0.00	-72.00	-72.00	-72.00

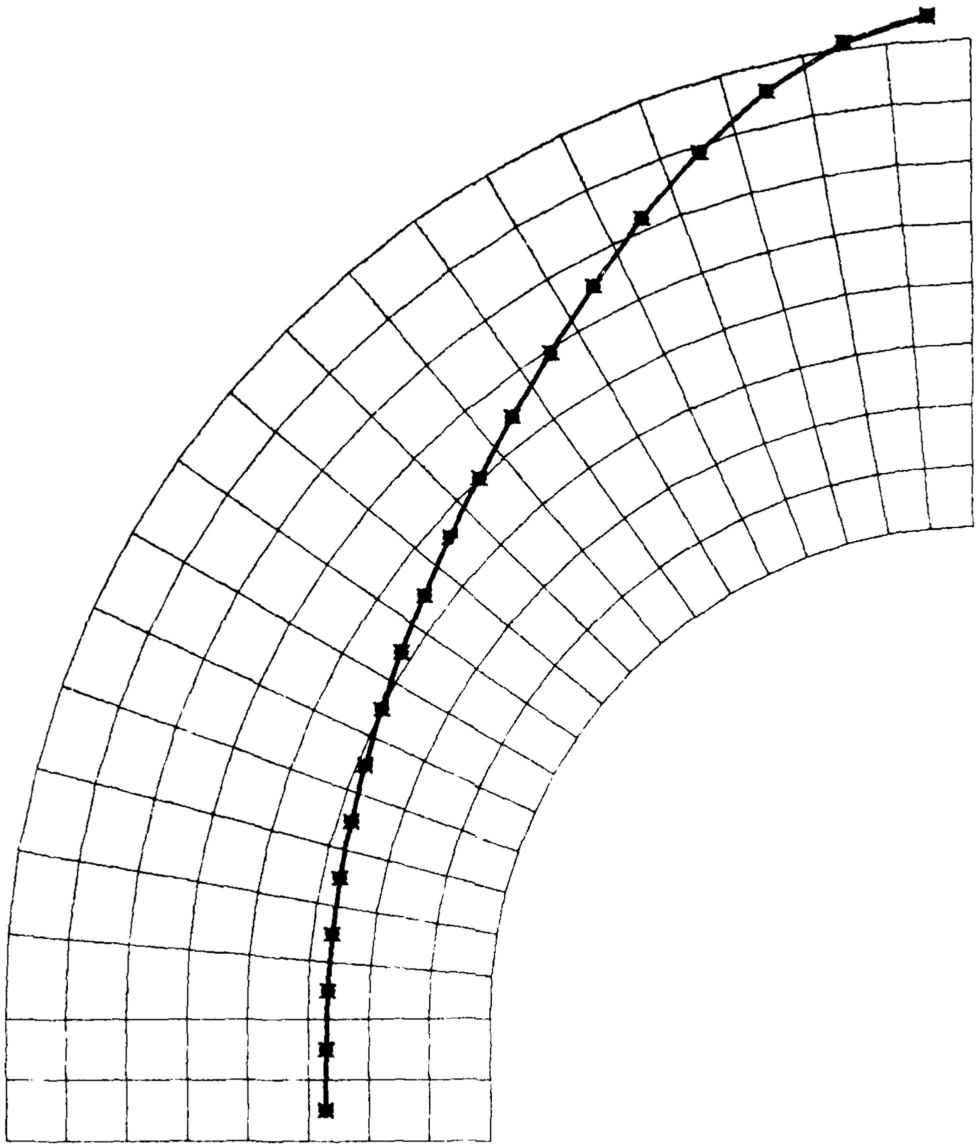


Figure 14: Line of thrust for conduit 2 with Wx/Wy = 0.25

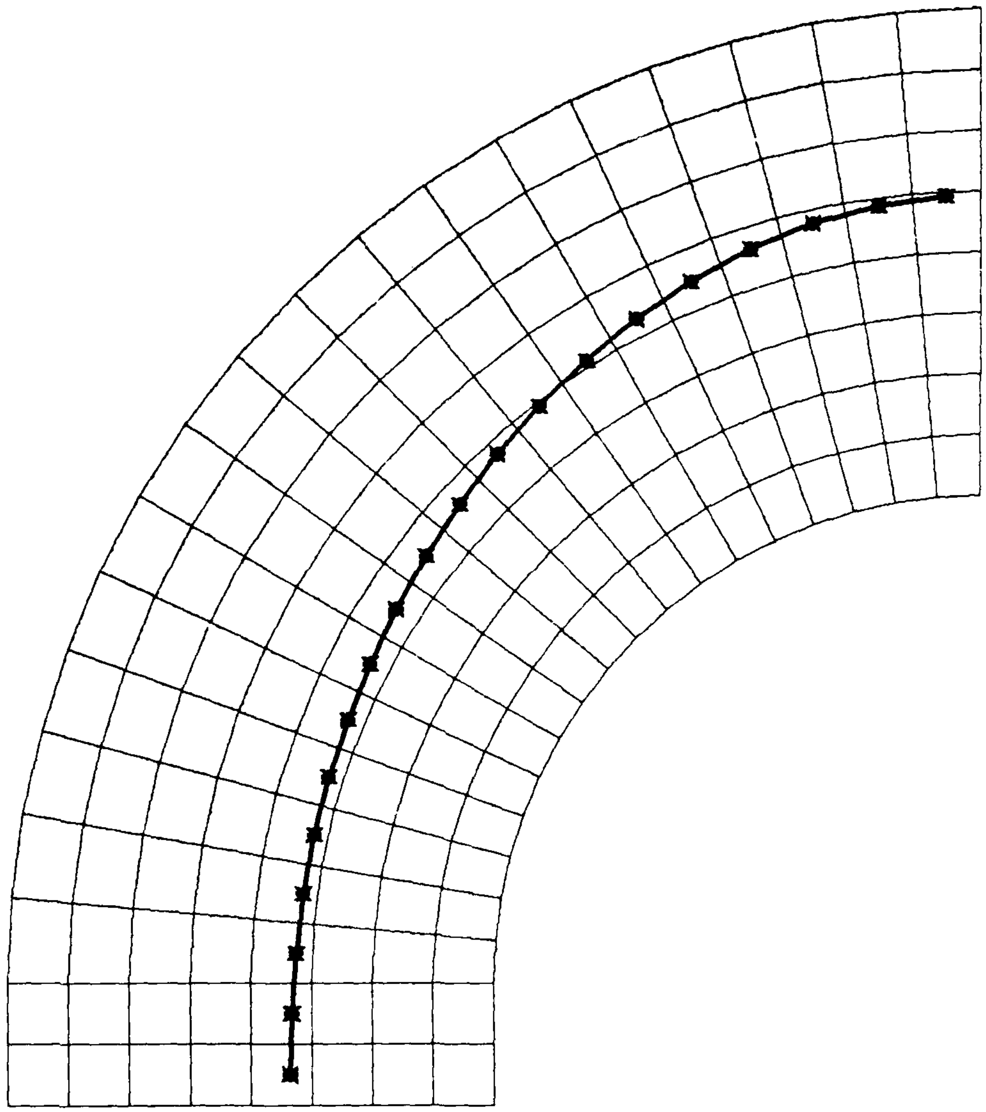


Figure 15: Line of thrust for conduit 2 with $W_x/W_y = 0.50$

2.4 NONDIMENSIONAL FACTORS FOR CALCULATING FORCE RESULTANTS

Force resultants for conduits having the same geometry are functions of their size. Therefore, it is possible to express the force resultants in a parametric form using parameters which define the geometric shape.

The geometry of an oblong conduit can be represented by two variables λ and μ where λ is the ratio of R_0 over R_i and μ is the ratio of H over S (Figure 1). Then, the force resultants of a unit thick conduit may be written in the following form.

BENDING MOMENT $= W * R_i^2 * \alpha$

SHEAR FORCE $= W * R_i * \beta$

THRUST $= W * R_i * \gamma$

where W is the intensity of the uniformly distributed load, R_i is the inner radius of the conduit and α, β, γ are scalar coefficients.

Tables 15 to 17 list the values of α, β and γ for conduit 1 which has $\lambda = 1.4$ and $\mu = 0.5$. Tables 18 to 20 list the values of α, β and γ for conduit 2 which has $\lambda = 2.0$ and $\mu = 2.0$. Tables for other combinations of values of λ, μ can be easily generated.

TABLE 15

Nondimensional factor α at various sections of conduit 1

SECTION	HORIZONTAL LOAD = 1/UNIT AREA			VERTICAL LOAD = 1/UNIT AREA		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	92.92	93.05	93.10	-57.19	-57.23	-57.24
2	90.83	90.97	91.02	-55.64	-55.68	-55.72
3	86.72	86.86	86.93	-52.64	-52.66	-52.69
4	80.71	80.87	80.94	-48.21	-48.27	-48.30
5	72.98	73.16	73.24	-42.58	-42.65	-42.68
6	63.75	63.93	64.02	-35.91	-35.98	-36.02
7	53.28	53.44	53.51	-28.44	-28.48	-28.52
8	41.81	41.94	41.99	-20.37	-20.39	-20.41
9	29.60	29.67	29.71	-11.96	-11.95	-11.93
10	16.91	16.94	16.92	-3.43	-3.38	-3.34
11	4.02	3.98	3.95	4.97	5.06	5.12
12	-8.84	-8.92	-9.00	13.00	13.14	13.21
13	-21.37	-21.49	-21.60	20.46	20.60	20.68
14	-33.35	-33.51	-33.62	27.08	27.24	27.32
15	-44.52	-44.69	-44.82	32.68	32.84	32.91
16	-54.65	-54.83	-54.95	37.05	37.19	37.28
17	-63.54	-63.72	-63.84	40.05	40.20	40.28
18	-71.06	-71.24	-71.36	41.62	41.76	41.83
19	-77.00	-77.19	-77.32	42.06	42.20	42.29
20	-81.26	-81.48	-81.60	42.06	42.20	42.29
21	-84.11	-84.32	-84.46	42.06	42.20	42.29
22	-85.55	-85.76	-85.90	42.06	42.20	42.29

TABLE 16

Nondimensional factor β at various sections of conduit 1

SECTION	HORIZONTAL LOAD = 1/UNIT AREA			VERTICAL LOAD = 1/UNIT AREA		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	0.95	0.95	0.95	-0.74	-0.74	-0.74
2	2.82	2.82	2.81	-2.18	-2.18	-2.18
3	4.62	4.61	4.61	-3.57	-3.56	-3.56
4	6.29	6.28	6.28	-4.83	-4.83	-4.83
5	7.80	7.80	7.79	-5.95	-5.95	-5.95
6	9.12	9.11	9.11	-6.89	-6.89	-6.99
7	10.20	10.20	10.20	-7.62	-7.61	-7.61
8	11.04	11.03	11.03	-8.11	-8.11	-8.11
9	11.60	11.60	11.60	-8.36	-8.36	-8.36
10	11.90	11.90	11.90	-8.36	-8.36	-8.36
11	11.91	11.91	11.91	-8.11	-8.11	-8.11
12	11.65	11.65	11.65	-7.61	-7.61	-7.61
13	11.14	11.14	11.13	-6.88	-6.88	-6.88
14	10.38	10.38	10.38	-5.95	-5.94	-5.94
15	9.41	9.40	9.40	-4.83	-4.82	-4.82
16	8.25	8.24	8.24	-3.56	-3.56	-3.56
17	6.95	6.94	6.94	-2.18	-2.18	-2.18
18	5.54	5.54	5.55	-0.74	-0.74	-0.74
19	4.20	4.20	4.20	0.00	0.00	0.00
20	3.00	3.00	3.00	0.00	0.00	0.00
21	1.80	1.80	1.80	0.00	0.00	0.00
22	0.60	0.60	0.60	0.00	0.00	0.00

TABLE 17

Nondimensional factor γ at various sections of conduit 1

SECTION	HORIZONTAL LOAD = 1/UNIT AREA			VERTICAL LOAD = 1/UNIT AREA		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	-21.49	-21.49	-21.51	-0.08	-0.07	-0.07
2	-21.20	-21.20	-21.21	-0.33	-0.32	-0.32
3	-20.61	-20.63	-20.64	-0.84	-0.83	-0.83
4	-19.77	-19.79	-19.79	-1.57	-1.56	-1.56
5	-18.68	-18.69	-18.71	-2.52	-2.51	-2.49
6	-17.39	-17.40	-17.41	-3.63	-3.63	-3.61
7	-15.92	-15.93	-15.93	-4.89	-4.88	-4.88
8	-14.31	-14.32	-14.33	-6.25	-6.25	-6.25
9	-12.61	-12.63	-12.63	-7.69	-7.68	-7.68
10	-10.88	-10.88	-10.89	-9.13	-9.13	-9.13
11	-9.15	-9.15	-9.15	-10.56	-10.56	-10.56
12	-7.44	-7.44	-7.44	-11.93	-11.93	-11.93
13	-5.83	-5.83	-5.81	-13.19	-13.19	-13.19
14	-4.33	-4.33	-4.33	-14.31	-14.31	-14.31
15	-3.01	-3.00	-3.00	-15.24	-15.24	-15.24
16	-1.88	-1.87	-1.87	-15.97	-15.97	-15.99
17	-0.97	-0.96	-0.75	-16.48	-16.48	-16.48
18	-0.29	-0.29	-0.28	-16.73	-16.73	-16.73
19	0.0	0.0	0.0	-16.80	-16.80	-16.80
20	0.0	0.0	0.0	-16.80	-16.80	-16.80
21	0.0	0.0	0.0	-16.80	-16.80	-16.80
22	0.0	0.0	0.0	-16.80	-16.80	-16.80

TABLE 18

Nondimensional factor α at various sections of conduit 2

SECTION	HORIZONTAL LOAD = 1/UNIT AREA			VERTICAL LOAD = 1/UNIT AREA		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	105.54	105.32	105.01	-71.83	-72.10	-72.38
2	103.01	102.78	102.45	-69.70	-69.97	-70.23
3	98.00	97.75	97.43	-65.50	-65.47	-66.02
4	90.66	90.40	90.06	-59.34	-59.95	-59.86
5	81.17	80.89	80.54	-51.44	-51.67	-51.92
6	69.78	69.48	69.12	-42.01	-42.22	-42.47
7	56.80	56.48	56.11	-31.36	-31.54	-31.78
8	42.58	42.22	40.83	-19.79	-19.91	-20.17
9	27.47	27.08	26.67	-7.66	-7.80	-8.01
10	11.87	11.46	11.04	4.66	4.53	4.34
11	-3.82	-4.26	-4.69	16.79	16.69	16.50
12	-19.19	-19.66	-20.11	28.36	28.28	28.11
13	-33.87	-34.37	-34.83	39.01	38.96	38.80
14	-47.50	-48.02	-48.50	48.43	48.40	48.24
15	-59.78	-60.32	-60.81	56.34	56.32	56.18
16	-70.42	-70.99	-71.49	62.51	62.49	62.36
17	-79.23	-79.81	-80.32	66.74	66.74	66.61
18	-86.07	-86.66	-87.18	68.97	68.98	68.84
19	-90.79	-91.39	-91.91	69.72	69.72	69.60
20	-93.03	-93.63	-94.17	69.77	69.77	69.64

TABLE 19

Nondimensional factor β at various sections of conduit 2

SECTION	HORIZONTAL LOAD = 1/UNIT AREA			VERTICAL LOAD = 1/UNIT AREA		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	1.17	1.17	1.17	-1.04	-1.04	-1.04
2	3.49	3.49	3.49	-3.10	-3.10	-3.10
3	5.71	5.71	5.71	-5.06	-5.06	-5.06
4	7.77	7.77	7.77	-6.87	-6.87	-6.87
5	9.52	9.62	9.62	-8.47	-8.47	-8.47
6	11.20	11.20	11.20	-9.82	-9.82	-9.82
7	12.47	12.47	12.47	-10.86	-10.86	-10.86
8	13.40	13.40	13.40	-11.57	-11.57	-11.57
9	13.96	13.96	13.96	-11.94	-11.94	-11.94
10	14.15	14.15	14.15	-11.94	-11.94	-11.94
11	13.95	13.95	13.95	-11.57	-11.57	-11.57
12	13.39	13.39	13.39	-10.86	-10.86	-10.86
13	12.47	12.47	12.47	-9.82	-9.82	-9.82
14	11.24	11.24	11.24	-8.47	-8.47	-8.47
15	9.73	9.73	9.73	-6.87	-6.87	-6.87
16	7.99	7.99	7.99	-5.07	-5.07	-5.07
17	6.08	6.08	6.08	-3.11	-3.11	-3.11
18	4.04	4.05	4.05	-1.05	-1.05	-1.05
19	2.25	2.25	2.25	0.00	0.00	0.00
20	0.75	0.75	0.75	0.00	0.00	0.00

TABLE 20

Nondimensional factor γ at various sections of conduit 2

SECTION	HORIZONTAL LOAD = 1/UNIT AREA			VERTICAL LOAD = 1/UNIT AREA		
NO.	.41%STEEL	.67%STEEL	.87%STEEL	.41%STEEL	.67%STEEL	.87%STEEL
1	-26.86	-26.87	-26.88	-0.10	-0.10	-0.09
2	-26.48	-26.49	-26.49	-0.47	-0.47	-0.47
3	-25.72	-25.73	-25.74	-1.18	-1.17	-1.17
4	-24.62	-24.62	-24.63	-2.22	-2.21	-2.21
5	-23.19	-23.20	-23.20	-3.55	-3.55	-3.55
6	-21.49	-21.49	-21.50	-5.15	-5.15	-5.15
7	-19.56	-19.56	-19.56	-6.95	-6.95	-6.94
8	-17.45	-17.46	-17.46	-8.91	-8.90	-8.90
9	-15.24	-15.24	-15.24	-10.96	-10.95	-10.95
10	-12.97	-12.97	-12.97	-13.03	-13.03	-13.03
11	-10.72	-10.72	-10.72	-15.09	-15.09	-15.09
12	-8.56	-8.55	-8.55	-17.04	-17.05	-17.05
13	-6.53	-6.52	-6.52	-18.85	-18.85	-18.85
14	-4.70	-4.70	-4.69	-20.44	-20.44	-20.45
15	-3.12	-3.11	-3.11	-21.78	-21.78	-21.78
16	-1.83	-1.82	-1.82	-22.82	-22.82	-22.83
17	-0.86	-0.85	-0.85	-23.53	-23.53	-23.53
18	-0.24	-0.23	-0.23	-23.90	-23.90	-23.90
19	0.00	0.00	0.00	-24.00	-24.00	-24.00
20	0.00	0.00	0.00	-24.00	-24.00	-24.00

SECTION III

DISCUSSION

Application of the finite element method to reinforced concrete conduits shows that the presence of steel has little effect on the force resultants but does influence the stress distribution in the vicinty of the reinforcement. Thus design can be based on force resultants obtained by analyzing the conduits ignoring the reinforcing steel. The presence of steel would also increase the conduit stiffness somewhat and result in slightly reduced displacements.

For conduits of a given geometric shape, it is possible to parametrically represent the force resultants. Tables of moment, thrust and shear parameters for two shapes have been included in this report. Tables for other values can be easily generated using an appropriate finite element technique.

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